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[KIND OF ARTICLE] SPECIFICATION 1

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[KIND OF DOCUMENT] SPECIFICATION

[TITLE OF INVENTION]

METHOD OF WELDING SINTERED ALUMINUM ALLOYS

5 [WHAT IS CLAIMED IS]

[CLAIM 1] A method of welding a sintered aluminum alloy, characterized by friction stir welding a sintered piece prepared by compressing and sintering quenched aluminum alloy powder.

[CLAIM2] The welding method of Claim 1, wherein the sintered
10 piece is composite material prepared by compressing and sintering a mixture of quenched aluminum alloy powder with ceramic particle.

[CLAIM3] The welding method of Claim 3, wherein the ceramic particle has an average size of 10 μm or less.

15 [DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[INDUSTRIAL APPLICATION]

The invention relates to a method of welding parts made of sintered aluminum alloys or aluminum composite material.

20 [0002]

[PRIOR ARTS]

Sintered aluminum alloys are manufactured by compressing and sintering aluminum alloy powder. Various properties, e.g. strength, heat-resistance, abrasion-resistance, Young's modulus and low thermal expansion
25 coefficient, are imparted to the sintered aluminum alloys by selection and designing of alloying compositions and/or improvement of processing, so that the sintered aluminum alloys are employed in various fields. Especially, sintered alloy parts, which are made of aluminum alloy powder prepared by melt quenching process, retain fine metallurgical structures originated in the

powder preparation, and exhibit good mechanical properties due to the fine metallurgical structures.

However, the powder metallurgy puts restrictions on profiles of sintered alloy parts. Therefore, aluminum alloy pieces, which are compressed
5 and sintered to tentative profiles, are welded together to fabricate objective profiles suitable for use. Arc-welding, e.g. MIG or TIG welding, is a representative method for welding the aluminum alloy pieces.

For instance, sintered pieces, which are prepared by compressing and sintering aluminum powder mixed with ceramic particles for impartment of
10 special properties, are heat-treated and then welded by a conventional welding method, as disclosed JP 2002-504186T.

[0003]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

When aluminum alloy pieces are arc-welded together, big electricity
15 shall be supplied to the aluminum alloy pieces due to high electric and thermal conductivity of the aluminum alloy. Generation of heat during welding causes various defects, e.g. deformation derived from thermal strain, reduction of strength at heat-affected zones or blowholes. Especially, sintered aluminum alloy parts occludes hydrogen therein at a rate of 20-30 cc/100 g
20 in an insufficiently degassed state. The occlusion rate is very higher than a conventional cast alloy part (less than 1 cc/100 g), resulting in formation of numerous blowholes during welding. Although hydrogen occlusion is reduced by vacuum degassing prior to sintering or by sintering in a vacuum atmosphere, hydrogen still remains in sintered alloy parts at a rate of 1-5
25 cc/100 g. As a result, blowholes are often formed due to the residual hydrogen. If the degassing process is continued in a vacuum atmosphere for a long while, elements with low vapor pressure are unfavorably discharged from surfaces of alloy powder. The long-term heating also coarsens metallurgical structures. Moreover, parts to be welded are melted according

to a conventional welding process, so that metallurgical structures are coarsened at the melted parts and the vicinities, resulting in reduction of strength at the weld joints compared with other parts. Furthermore, the coarsening cancels advantages of fine metallurgical structures originated in quenched alloy powder.

[0004]

A welding process often uses filler material, for welding dispersion-strengthened material comprising an aluminum alloy to which ceramic particles are dispersed. When such filler material does not disperse ceramic particles as reinforcement therein, weld joints are formed in a reinforcement-free state and so weakened in comparison with other parts.

The present invention is accomplished to overcome the above-mentioned problems, aiming at provision of welded bodies of sintered aluminum alloys without substantial difference in strength between weld joints and the other parts.

[0005]

[MEANS TO SOLVE THE PROBLEMS]

The invention is characterized by friction stir welding sintered pieces, which are prepared by compressing and sintering quenched aluminum alloy powder to a certain profile.

The sintered pieces may be composite material of quenched aluminum alloy powder with ceramic particle. The ceramic particle is preferably of 10 μm or less in average size.

The friction stir welding is performed under conditions of: a rotation rate of the pin within a range of 500-3000 r.p.m., a travel speed of 200-1000 mm/minute and a pushing depth of the shoulder within a range of 0-1 mm.

The inventive welding process is applicable not only for welding sintered aluminum alloy pieces together but also for welding a sintered

aluminum alloy piece to a cast aluminum alloy piece.

[0006]

[FUNCTION]

A friction stir welding process uses a rotator 2 having a pin 24
5 concentrically fixed to its top end, as shown in Fig. 1 (disclosed in JP 9-
508073 T). The rotator 2 is rotated and pressed onto workpieces 3 and 4, so
as to thrust the pin 24 into a space between the workpieces 3 and 4. Edges of
the workpieces 3 and 4 are heated by friction against the pin 24 and stirred
by rotation of the pin 24. Metal at the edges of the workpieces 3 and 4 is
10 plastically fluidized by the heat and stirring and mixed between the
workpieces 3 and 4. Since heat is rapidly diffused after passage of the pin 24,
the metal is solidified and a weld joint 5 is formed between the workpieces 3
and 4. In Fig. 1, the numeral 22 is an upper part for connecting the rotator to
a driving source, the numeral 23 is a lower part for fixing the pin 24, and the
15 numeral 1 is a non-consumable probe provided with the rotator 2.

In the friction stir welding, a weld joint is formed by plastically
fluidizing and mixing metal with a friction heat and a strong stirring power
at edges of workpieces, but the metal is not melted as noted in arc-welding.
Therefore, the weld joint is not heated up to an excess high temperature,
20 which leads to coarsening of metallurgical structure or formation of
blowholes, but retains high mechanical strength.

Even when particle-dispersed composite pieces are friction stir
welded, a weld joint is formed by mixing the composite material without
insertion of a filler. As a result, the weld joint retains high mechanical
25 strength, since it keeps a particle-dispersed matrix without thermal
deformation or blowholes.

In order to ensure plastic fluidization of metal in a welding zone,
ceramic particle mixed in composite material is preferably 10 μm or less in
average size. If ceramic particle bigger than 10 μm is dispersed in the

composite material, fluidization of metal in a welding zone becomes insufficient, resulting in heterogeneous distribution of the ceramic particle and strength reduction of a weld joint. The coarse ceramic particle also abrades the rotating pin.

5 [0007]

[EMBODIMENT OF THE INVENTION]

Quenched aluminum alloy powder is preferably prepared by gas atomizing process. The aluminum alloy powder preferably has an average particle size of 20-100 μm . Fine alloy powder less than 20 μm is difficult to
10 manufacture and to handle due to poor fluidity. When coarse alloy powder above 100 μm is compressed and sintered on the contrary, a metallurgical structure of a sintered body is coarsened, resulting in poor mechanical strength in spite of a sintered alloy.

The alloy powder is poured in an aluminum can or subjected to cold
15 isostatic molding or spark plasma sintering for improvement of handleability. In the case where a workpiece to be welded is composite material, ceramic particle is added to the alloy powder at this stage. The ceramic particle to be mixed in the alloy powder is selected from the group consisting of Al_2O_3 , ZrO_2 , SiC , B_4C , WC , AlN , Si_3N_4 , BN and TiB_2 . Two or more of ceramic
20 particles may be mixed in the alloy powder. A mixing rate of ceramic particle is determined to a value suitable for impartment of an objective function.

[0008]

The aluminum alloy powder, after being pre-treated for improvement of handleability, is pressure sintered. The alloy powder may be subjected to
25 degassing treatment such as vacuum suction in prior to pressure sintering. The alloy powder is preferably degassed while being heated, so as to accelerate removal of gases and to promote partial sintering reaction. Concretely, the alloy powder is heated at a temperature higher than 200°C (preferably 450°C) during degassing.

Pressure sintering may be hot working, e.g. extruding, forging or rolling, other than conventional sintering in a pressurized state. Such multi-stage process may be employed as hot-extruding or hot-rolling at first and then hot-forging.

5 [0009]

Pressure sintered pieces provided as the above are then friction stir welded. The sintered pieces may be heat-treated according to the purpose in prior to or after the friction stir welding.

Friction stir welding is preferably performed under conditions of: a
10 rotation rate of the rotating pin within a range of 500-3000 r.p.m. at a travel speed of 200-1000 mm/minute and a pushing depth of a rotary shoulder within a range of 0-1 mm.

A rotation rate above 3000 r.p.m. or a travel speed slower than 200 mm/minute causes overheating and melting of parts to be welded, resulting
15 in formation of coarse metallurgical structure. On the contrary, a rotation rate less than 500 r.p.m. or a travel speed above 1000 mm/minute causes too much load applied to a rotator and breakdown of a rotating pin. A pushing depth of the rotator shoulder less than 0 mm means that the rotator shoulder is not in contact with workpieces and leads to formation of a weld joint in an
20 unstrained state. The unstrained welding allows plastic fluidization of metal over a broad range inappropriate for formation of a normal welded structure, resulting in poor mechanical strength. If a pushing depth of the rotator shoulder exceeds 1 mm on the contrary, the rotating pin is often broken down due to application of heavy load.

25 In order to enhance weld strength of a ceramic particle-dispersed sintered body, it is preferable to increase a ratio of ceramic particle, e.g. Al_2O_3 , ZrO_2 or SiC , dispersed in a weld joint. In order to improve neutron absorption, it is preferable to increase a ratio of B_4C dispersed in a weld joint. For the purpose, an aluminum alloy, which disperses ceramic particle

therein at a relatively high ratio, is separately prepared and shaped to a welding aid with a proper profile. The welding aid is sandwiched between or mounted on workpieces to be friction stir welded.

[0010]

5 [EXAMPLE]

Example 1:

Each aluminum alloy of a composition in Table 1 was pulverized to 55 μm in average particle size by air atomization method.

10 The alloy powder was compressed to a cylindrical billet of 95 mm in diameter by cold isostatic molding with a pressure of 1200 kg/cm². The billet was degassed and sintered by 2 hours heating at 560°C in vacuum. After the sintered billet was cooled to a room temperature, it was reheated to 500°C by an induction heater and then extruded (i.e., pressure sintered) to a flat sheet of 4 mm in thickness. Thereafter, the sheet was subjected to T6 treatment
15 (solution heating at 520°C for one hour, water quenching and then aging at 180°C for 6 hours).

The heat-treated sheet was friction stir welded together, under conditions of: a rotation rate of 1500 r.p.m., a travel speed of 400 mm/minute and a pushing depth of 0.5 mm.

20 Test pieces, which involved a weld joint, were sampled from the welded sheet and subjected to a tensile test. Test results are shown in Table 2.

For comparison, extruded parts with C-shaped section were MIG welded together, using a filler JIS A4043. Test pieces, which involved a weld
25 joint, were sampled from the welded body and subjected to the same tensile test. Test results are also comparatively shown in Table 2.

[0011]

Table 1: Chemical Composition of Samples (mass %)

| Alloy No. | Si | Fe | Mg | Cu | Cr | Sm | Gd |
|-----------|-----|-----|-----|-----|-----|-----|-----|
| 1 | 0.6 | 0.2 | 0.8 | 0.3 | 0.2 | — | — |
| 2 | 0.8 | 4.8 | 0.9 | 0.2 | 0.3 | — | — |
| 3 | 2.0 | 2.0 | 2.5 | 1.0 | — | — | 2.0 |
| 4 | 2.0 | 2.0 | 2.5 | 1.5 | — | 5.3 | — |
| 5 | 25 | 0.2 | 0.9 | 0.2 | 0.3 | — | — |

[0012]

5

Table 2: Welding Method and Mechanical Properties

| Alloy No. | Welding Method | Tensile Strength (MPa) | Yield Strength (MPa) | Elongation (%) | Note |
|-----------|----------------|------------------------|----------------------|----------------|----------------------|
| 1 | FSW | 380 | 367 | 10.6 | Inventive Examples |
| 2 | FSW | 412 | 387 | 8.7 | |
| 3 | FSW | 369 | 342 | 5.8 | |
| 4 | FSW | 325 | 309 | 4.9 | |
| 5 | FSW | 381 | 341 | 0.7 | |
| 1 | MIG | 121 | immeasurable | immeasurable | Comparative Examples |
| 2 | MIG | 89 | immeasurable | immeasurable | |
| 3 | MIG | 79 | immeasurable | immeasurable | |
| 4 | MIG | 111 | immeasurable | immeasurable | |
| 5 | MIG | immeasurable | immeasurable | immeasurable | |

FSW : Friction stir welding

MIG : MIG welding

[0013]

Results in Table 2 prove that the inventive examples, i.e. friction stir welded pieces, had high strength.

On the other hand, the comparative examples, i.e. MIG welded
5 pieces, were extremely inferior in mechanical strength and elongation, so that the tensile test itself was difficult. The inferior properties are caused by formation of blowholes and coarsening of metallurgical structure. In fact, when the MIG welded pieces were inspected by ultrasonic irradiation, many defects, probably derived from blow holes, were detected.

10 When the friction stir weld joint was inspected by ultrasonic irradiation, no defects were detected. A fracture surface formed by the tensile test was a normal ductile fracture plane.

[0014]

Example 2:

15 Several powdery compositions were prepared by mixing aluminum alloy powders Nos. 2 and 3 in Table 1 with ceramic particles, Al_2O_3 , SiC , B_4C and AlN , of average particle sizes at mixing ratios in Table 3. Each composition was compressed, extruded and welded by the same way as
20 **Example 1.** The welded peaces were subjected to the same tensile test as

Results are also shown in Table 3.

[0015]

Table3: Mixing Ratios of Ceramic Particles and Mechanical Properties

| Alloy No. | Ceramic Particles | | Welding Method | Tensile Strength (MPa) | Yield Strength (MPa) | Elongation (%) | Note |
|-----------|-------------------------|---------------------------------|-----------------------|------------------------|----------------------|----------------|----------------------|
| | Kind | Particle size (μm) | Mixing Ratio (mass %) | | | | |
| 2 | Al_2O_3 | 8 | 8 | 440 | 420 | 6.5 | Inventive Examples |
| 2 | Al_2O_3 | 20 | 8 | 410 | 380 | 4.3 | |
| 2 | SiC | 8 | 15 | 480 | 455 | 2.0 | |
| 3 | B_4C | 9 | 5 | 435 | 412 | 4.8 | |
| 3 | AlN | 8 | 5 | 398 | 374 | 6.0 | |
| 2 | Al_2O_3 | 8 | 8 | 165 | — | — | Comparative Examples |
| 2 | SiC | 15 | 15 | 140 | — | — | |
| 3 | B_4C | 9 | 5 | 280 | 130 | 1.5 | |
| 3 | AlN | 8 | 5 | 175 | 110 | 1.0 | |

FSW : Friction stir welding

MIG : MIG welding

[0016]

It is noted from Table 3 that the inventive examples, i.e. friction stir welded pieces, had high tensile strength even at weld joints. The welded piece, made of the alloy No. 1 dispersing ceramic particle of 10 μm or less in size, had higher strength than the welded piece, made of the alloy No. 2 dispersing ceramic particle above 10 μm in size. Moreover, it was recognized that a rotating pin, which was used for friction stir welding the alloy No. 2 dispersing ceramic particle above 10 μm in size, was heavily abraded in comparison with other examples.

On the other hand, the comparative examples, i.e. MIG welded pieces, were extremely inferior in mechanical strength and elongation, so that the tensile test itself was difficult. The inferior properties are caused by formation of blowholes and coarsening of metallurgical structure. In fact, when the MIG welded pieces were inspected by ultrasonic irradiation, many defects, probably derived from blow holes, were detected. No ceramic particles were observed on sectional surface.

When the inventive friction stir weld joint was inspected by ultrasonic irradiation, no defects were detected.

[0017]

[EFFECT OF THE INVENTION]

According to the present invention as above-mentioned, sintered pieces of quenched aluminum alloy powder are friction stir welded, and a weld joint is not melted so as to inhibit formation of blowholes and coarsening of metallurgical structure. As a result, the sintered alloy piece can be welded without any decrease of its original mechanical strength. Especially, composite material, dispersing ceramic particles as reinforcement therein, can be welded according to the invention, so as to provide a welded structure, which retains an original particle-strengthening effect.

Therefore, application of sintered aluminum alloys and composite materials is greatly expanded to various uses.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] an explanatory view of a friction stir welding process (cited from JP
5 9-508073T)

[KIND OF DOCUMENT] ABSTRACT

[ABSTRACT]

[OBJECT] To provide sintered pieces being welded together while retaining intrinsic properties of the sintered aluminum alloy.

5 [CONSTITUTION]

Sintered pieces of quenched aluminum alloy powder are friction stir welded together.

The weld joint is formed without melting, so as to inhibit formation of blowholes or coarsening of metallurgical structure, retaining intrinsic
10 properties of the sintered aluminum alloy.

[DESIGNATION OF DRAWINGS] none

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Inventor: Shigeru OKANIWA et al.

Entitled: METHOD OF WELDING SINTERED ALUMINUM ALLOYS

VERIFICATION OF TRANSLATION

Assistant Commissioner for Patents
Washington, D.C. 20231

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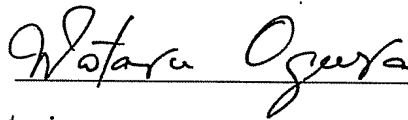
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